Chapter 3
Greenhouse Gas Emissions

Summary Statistics from Tables in this Chapter

Source			
Table 3.1	Carbon emissions (million metric tonnes)	1990	1999
	United States	*1,352*	*1,517*
	China	*617*	*669*
	Germany	*271*	*230*
	Japan	*269*	*307*
	United Kingdom	*164*	*151*
	India	*153*	*242*
	France	*102*	*109*
Table 3.4	Transportation share of U.S. carbon dioxide emissions from fossil fuel consumption		
	1985		*30.9%*
	1990		*32.0%*
	2000		*33.0%*
Table 3.6	GREET model greenhouse gas emissions		
	Gasoline baseline		*469 grams/mile*
	Natural gas		*-23.1%*
	E90: corn ethanol		*-31.0%*
	E90: cellulosic ethanol		*-77.1%*
	EV: US mix		*-44.5%*
	Fuel cell: hydrogen, central plant, natural gas		*-48.7%*
	Fuel cell: hydrogen, central electrolysis, renewables		*-90.7%*
	Fuel cell: hydrogen, station electrolysis, US mix		*43.3%*

Table 3.1
World Carbon Emissions, 1990 and 1999

	1990		1999	
	Million metric tons	Percent of emissions from oil use	Million metric tons	Percent of emissions from oil use
Industrialized countries	2,849	49%	3,129	49%
United States	1,352	44%	1,517	43%
Canada	126	48%	150	45%
Mexico	84	77%	101	75%
United Kingdom	164	40%	151	42%
France	102	66%	109	66%
Germany	271	38%	230	45%
Italy	112	66%	121	61%
Netherlands	58	47%	64	48%
Other Western Europe	223	62%	264	66%
Japan	269	67%	307	60%
Other industrialized countries	88	42%	115	41%
Eastern Europe	1,337	30%	810	25%
Developing countries	1,641	41%	2,158	45%
China	617	15%	669	24%
India	153	29%	242	30%
Other developing countries	871	61%	1,247	59%
Total World	5,827	43%	6,097	44%

Source:
U.S. Department of Energy, Energy Information Administration, *International Energy Outlook 2001*, Washington, DC, March 2002, Tables A10 and A11.

Global Warming Potentials (GWP) were developed to allow comparison of each greenhouse gas' ability to trap heat in the atmosphere relative to carbon dioxide. Extensive research has been performed and it has been discovered that the effects of various gases on global warming are too complex to be precisely summarized by a single number. Further understanding of the subject also causes frequent changes to estimates. Despite that, the scientific community has developed approximations, which are shown below. Most analysts use the 100-year time horizon.

Table 3.2
Numerical Estimates of Global Warming Potentials Compared With Carbon Dioxide
(kilogram of gas per kilogram of carbon dioxide)

Gas	Lifetime (years)	Global warming potential direct effect for time horizons of 20 years	100 years	500 years
Carbon Dioxide	5-200[a]	1	1	1
Methane	12	62	23	7
Nitrous Oxide	114	275	296	156
HFCs[b], PFCs[c], and Sulfur Hexafluoride				
HFC-23	260	9,400	12,000	10,000
HFC-125	29	5,900	3,400	1,100
HFC-134a	14	3,300	1,300	400
HFC-152a	1	410	120	37
HFC-227ea	33	5,600	3,500	1,100
Perfluoromethane (CF_4)	50,000	3,900	5,700	8,900
Perfluoroethane (C_2F_6)	10,000	8,000	11,900	18,000
Sulfur hexafluoride (SF_6)	3,200	15,100	22,200	32,400

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2000*, Washington, DC, November 2001, Table 3. Original source: Intergovernmental Panel on Climate Change. (Additional resources: www.eia.doe.gov, www.ipcc.ch)

Note:
The typical uncertainty for global warming potentials is estimated by the Intergovernmental Panel on Climate Change ± 35 percent.

[a]No single lifetime can be defined for carbon dioxide due to different rates of uptake by different removal processes.
[b]Hydrofluorocarbons
[c]Perfluorocarbons

Carbon dioxide emissions in 2000 were 17% higher than in 1990. Carbon dioxide accounts for the majority of greenhouse gases.

Table 3.3
Estimated U.S. Emissions of Greenhouse Gases, 1990–2000

Greenhouse gas	Unit of measure[a]	1990	1995	1999	2000
Carbon dioxide	million metric tons of gas	4,969.4	5,273.5	5,630.7	5,805.5
	million metric tons of carbon	1,355.0	1,438.0	1,536.0	1,583.0
Methane	million metric tons of gas	31.7	31.1	28.7	28.2
	million metric tons of carbon (gwp)[b]	199.0	195.0	180.0	177.0
Nitrous oxide	million metric tons of gas	1.2	1.3	1.2	1.2
	million metric tons of carbon (gwp)[b]	94.0	101.0	100.0	99.0
HFCs, PFCs, and SF_6[c]	million metric tons of carbon (gwp)[b]	30.0	35.0	45.0	47.0

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 2000*, Washington, DC, November 2001, Tables ES1 andES2. (Additional resources: www.eia.doe.gov)

[a]Gases that contain carbon can be measured either in terms of the full molecular weight of the gas or just in terms of their carbon content. See Appendix B, Table B.5 for details.
[b]Based on global warming potential.
[c]HFC-hydrofluorocarbons. PFC-perfluorocarbons. SF_6-sulfur hexaflouride.

Gases which contain carbon can be measured in terms of the full molecular weight of the gas or just in terms of their carbon content. This table presents carbon content. The ratio of the weight of carbon to carbon dioxide is 0.2727. The transportation sector accounts for approximately one-third of carbon dioxide emissions.

Table 3.4
U.S. Carbon Dioxide Emissions from Fossil Energy Consumption by End-Use Sector, 1985–2000[a]
(million metric tons of carbon)

End use sector	1985	1990	1995	1996	1997	1998	1999	2000
Residential	245.8	257.0	277.9	229.9	292.8	293.7	298.8	313.4
Commercial	189.6	210.3	224.6	233.1	245.4	250.4	253.1	267.8
Industrial	424.1	452.7	461.1	476.7	481.5	469.5	465.8	465.7
Transportation	384.4	431.8	457.8	468.9	473.6	481.5	499.4	514.8
Percentage	30.9%	32.0%	32.2%	31.9%	31.7%	32.2%	32.9%	33.0%
Total energy	**1,243.9**	**1,351.7**	**1,421.3**	**1,471.9**	**1,493.3**	**1,495.2**	**1,517.1**	**1,561.7**

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 2000*, Washington, DC, November 2001, Table 5, and annual. (Additional resources: www.eia.doe.gov)

[a]Includes energy from petroleum, coal, and natural gas. Electric utility emissions are distributed across consumption sectors.

Most U.S. carbon dioxide emissions come from petroleum fuels (98%). Motor gasoline has been responsible for about 60% of U.S. carbon dioxide emissions over the last twenty years.

Table 3.5
U.S. Carbon Dioxide Emissions from Energy Use in the Transportation Sector, 1980–2000
(million metric tons of carbon)

	1980		1990		2000	
Fuel	Emissions	Percentage	Emissions	Percentage	Emissions	Percentage
			Petroleum			
Motor gasoline	238.1	62.9%	260.5	60.3%	301.5	58.6%
LPG[a]	0.3	0.1%	0.4	0.1%	0.2	0.1%
Jet fuel	42.0	11.1%	60.1	13.9%	68.5	13.3%
Distillate fuel	55.3	14.6%	75.7	17.5%	106.6	20.7%
Residual fuel	30.0	7.9%	21.9	5.1%	23.1	4.5%
Lubricants	1.8	0.5%	1.8	0.4%	1.8	0.3%
Aviation gas	1.2	0.3%	0.8	0.2%	0.7	0.1%
Subtotal	**368.7**	97.4%	**421.2**	97.5%	**502.5**	97.6%
			Other energy			
Natural gas	9.4	2.5%	9.8	2.3%	11.4	2.2%
Electricity[b]	0.3	0.1%	0.7	0.2%	0.9	0.2%
Total	**378.4**	100.0%	**432.8**	100.0%	**514.8**	100.0%

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 2000*, Washington, DC, November 2001, Table 8, and annual. (Additional resources: www.eia.doe.gov)

[a]Liquified petroleum gas.
[b]Share of total electric utility carbon dioxide emissions weighted by sales to the transportation sector.

The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model

The energy in greenhouse gas estimates of the most recent version (Beta Version 1.6) of the GREET model are displayed in the next table. The model estimates the full fuel-cycle emissions and energy use associated with various transportation fuels and advanced transportation technologies for light-duty vehicles. It calculates fuel-cycle emissions of **three greenhouse gases** (carbon dioxide, methane, and nitrous oxide) and five criteria pollutants (volatile organic compounds, carbon monoxide, nitrogen oxides, sulfur oxides, and particulate matter measuring 10 microns or less). **See Chapter 4 for the criteria pollutant data from GREET.** The model also calculates the total fuel-cycle energy consumption, fossil fuel consumption, and petroleum consumption using various transportation fuels. The fuel cycles that are included in the GREET model are:

- petroleum to conventional gasoline, reformulated gasoline, conventional diesel, reformulated diesel, liquefied petroleum gas, and electricity via residual oil;
- natural gas to compressed natural gas, liquefied natural gas, liquefied petroleum gas, methanol, Fischer-Tropsch diesel, dimethyl ether, hydrogen, and electricity;
- coal to electricity;
- uranium to electricity;
- renewable energy (hydropower, solar energy, and wind) to electricity;
- corn, woody biomass, and herbaceous biomass to ethanol;
- soybeans to biodiesel; and
- landfill gases to methanol.

For additional information about the GREET model, see *GREET 1.5 – Transportation Fuel-Cycle Model, Volume 1: Methodology, Development, Use and Results*, ANL/ESD-39, Vol. 1, August 1999, or contact:

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GREET Web Site:
http://www.transportation.anl.gov/ttrdc/greet/

A new version of GREET will be available soon. Check the web site for details.

Acronyms and Terms Used on Table 3.6

BD20	mixture of 20% biodiesel and 80% conventional diesel (by volume)
CA	California
CH4	methane
CIDI	compression ignition, direct injection
CIDIV	compression ignition, direct injection vehicle
CNG	compressed natural gas
CNGV	compressed natural gas vehicle
CO2	carbon dioxide
DME	dimethyl ether
E90	mixture of 90% ethanol and 10% gasoline (by volume)
EtOH	ethanol
EtOHV	ethanol vehicle
EV	electric vehicle
FCV	fuel-cell vehicle
FRFG	Federal reformulated gasoline
FT	Fischer-Tropsch
FTD	Fischer-Tropsch diesel
G.H2	gaseous hydrogen
GC	grid-connected (charge depleting)
GGE	gasoline gallon equivalent
GHGs	greenhouse gases
GI	grid-independent (charge sustaining)
GV	gasoline vehicle
HEV	hybrid electric vehicle
L.H2	liquid hydrogen
LS	low-sulfur
M90	mixture of 90% methanol and 10% gasoline by volume
MeOH	methanol
MeOHV	methanol vehicle
N2O	nitrous oxide
NA	North American
NE	northeast
NG	natural gas
NNA	non-North American
SI	spark ignition
urban	Emissions occurring within air quality control regions in the U.S. These regions have emission controls in place in order to meet or maintain air quality standards.
US	United States

Table 3.6
Fuel-Cycle Energy and Greenhouse Gas Emission Changes
of Alternative and Advanced Vehicle/Fuel Systems
(percentage relative to internal combustion engine vehicles
fueled with reformulated gasoline)

	GV: FRFG (btu/mile or grams/mile)	CNGV: NA NG	CNGV: NNA NG	Propane vehicle	M90 MeOHV: NA NG	M90 MeOHV: NNA NG	E90 EtOHV: corn	E90 EtOHV: cellulosic biomass	GI SI HEV: FRFG	GC SI HEV: FRFG
MPG - GGE	24.1	24.1	24.1	25.3	25.3	25.3	25.3	25.3	33.8	54.1
Total energy	5,891	-9.5%	1.2%	-16.2%	14.6%	16.3%	10.4%	53.8%	-28.6%	-40.7%
Fossil fuels	5,872	-9.7%	1.0%	-16.0%	14.9%	16.6%	-45.3%	-79.5%	-28.6%	-43.1%
Petroleum	4,665	-99.5%	-99.5%	-59.1%	-79.1%	-79.9%	-75.0%	-74.9%	-28.6%	-57.7%
CO2	446	-26.8%	-18.5%	-20.1%	-5.7%	-4.3%	-41.0%	-88.9%	-28.6%	-40.1%
CH4	0.684	111.0%	216.8%	-21.9%	-9.5%	8.5%	-27.6%	-63.3%	-25.9%	-39.4%
N2O	0.030	-49.6%	-46.4%	-3.1%	0.5%	1.3%	448.3%	474.8%	-1.6%	-29.2%
GHGs	469	-23.1%	-13.1%	-19.8%	-5.7%	-3.9%	-31.0%	-77.1%	-28.0%	-39.9%

	CIDIV: LS diesel	CIDIV: FTD, NA NG	CIDIV: FTD, NNA NG	CIDIV: BD20	GI CIDI HEV: LS diesel	GC CIDI HEV: LS diesel	EV: US mix	EV: NE US mix	EV: CA mix
MPG - GGE	29.6	29.6	29.6	29.6	41.0	57.7	84.4	84.4	84.4
Total energy	-21.7%	8.7%	10.4%	-19.0%	-43.6%	-47.2%	-45.1%	-46.2%	-50.6%
Fossil fuels	-21.7%	9.0%	10.8%	-19.1%	-43.6%	-49.6%	-52.5%	-55.6%	-61.9%
Petroleum	-10.4%	-99.0%	-98.5%	-25.5%	-35.4%	-59.7%	-98.4%	-97.5%	-99.7%
CO2	-17.1%	-13.4%	-12.1%	-28.4%	-40.2%	-44.6%	-43.5%	-53.4%	-61.5%
CH4	-40.4%	-40.3%	-24.9%	-44.2%	-56.6%	-56.3%	-48.8%	-36.3%	-43.2%
N2O	-42.3%	-44.9%	-30.0%	-34.1%	-43.3%	-57.0%	-84.1%	-87.1%	-88.6%
GHGs	-18.3%	-14.8%	-12.7%	-29.0%	-40.8%	-45.2%	-44.5%	-53.5%	-61.5%

	FCV: G.H2, central plant, NA NG	FCV: G.H2, central plant, NNA NG	FCV: G.H2, refueling station, NA NG	FCV: G.H2, refueling station, NNA NG	FCV: G.H2, central electrolysis, renewables	FCV: G.H2, station electrolysis, US generation mix
MPG - GGE	50.7	50.7	50.7	50.7	50.7	50.7
Total energy	-35.6%	-30.0%	-32.9%	-28.4%	-37.6%	40.5%
Fossil fuels	-36.6%	-31.0%	-33.2%	-28.6%	-91.9%	22.4%
Petroleum	-99.2%	-99.3%	-99.7%	-99.6%	-99.5%	-96.3%
CO2	-47.7%	-42.7%	-46.9%	-43.3%	-90.6%	44.7%
CH4	-50.1%	-4.3%	-36.2%	-3.3%	-89.5%	62.6%
N2O	-94.9%	-93.2%	-94.8%	-93.3%	-97.7%	-64.9%
GHGs	-48.7%	-42.6%	-47.5%	-43.2%	-90.7%	43.3%

(Table continued on next page)

Note:
See page preceding Table 3.6 for acronym definitions.

Table 3.6 (Continued)
Fuel-Cycle Energy and Emission Changes of Alternative and Advanced Vehicle/Fuel Systems
(percentage relative to intenal combustion engine vehicles fueled with reformulated gasoline)

	FCV: L.H2, central plant, NA NG	FCV: L.H2, central plant, NNA NG	FCV: L.H2, refueling station, NA NG	FCV: L.H2, refueling station, NNA NG	FCV: L.H2, central electrolysis, renewables	FCV: L.H2, station electrolysis, US generation mix
MPG - GGE	50.7	50.7	50.7	50.7	50.7	50.7
Total energy	-11.6%	-8.5%	12.4%	19.5%	-44.0%	105.3%
Fossil fuels	-11.4%	-8.4%	6.0%	12.9%	-98.7%	61.7%
Petroleum	-99.3%	-99.0%	-98.4%	-98.4%	-99.4%	-95.2%
CO2	-28.8%	-25.4%	-1.3%	2.4%	-98.8%	91.1%
CH4	-25.1%	-21.6%	6.5%	81.3%	-98.8%	114.7%
N2O	-86.2%	-85.5%	-84.3%	-82.7%	-99.6%	-53.7%
GHGs	-29.7%	-26.4%	-2.5%	2.9%	-98.8%	89.2%

	FCV: MeOH, NA NG	FCV: MeOH, NNA NG	FCV: gasoline	FCV: cellulosic EtOH	FCV: CNG, NA NG	FCV: CNG, NNA NG	FCV: FT naphtha, NNA NG	FCV: crude naphtha
MPG - GGE	42.2	42.2	37.4	39.3	37.4	37.4	37.4	37.4
Total energy	-28.7%	-27.4%	-35.5%	19.9%	-41.6%	-34.7%	-10.3%	-38.6%
Fossil fuels	-28.5%	-27.2%	-35.5%	-96.9%	-41.7%	-34.8%	-10.0%	-38.6%
Petroleum	-98.5%	-98.1%	-35.5%	-94.4%	-99.7%	-99.7%	-98.7%	-36.4%
CO2	-43.5%	-42.5%	-35.5%	-105.1%	-52.7%	-47.4%	-32.7%	-41.3%
CH4	-46.7%	-33.5%	-39.3%	-91.8%	15.0%	85.2%	-38.8%	-41.8%
N2O	-77.4%	-76.7%	-77.4%	338.7%	-79.1%	-77.0%	-79.9%	-78.6%
GHGs	-44.3%	-42.9%	-36.3%	-96.0%	-51.1%	-44.6%	-33.7%	-41.9%

Source:
Wang, Michael, Q., model results of Beta Version of GREET 1.6, Argonne National Laboratory, Argonne, IL, August, 2001.

Note:
See page preceding Table 3.6 for acronym definitions.